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Economic model for the production of spirit, inulin and syrup from the locally eco-friendly agave americana

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Abstract

Less than 3% Agave americana L. plant matrix constitute biodegradable fibers. In order to improve the economic viability of the plant, there is need to commercialize other products from the heart of the plant. The Analytic Hierarchy Process (AHP) was used to analyze a set of factors that affect agave production as well as possible alternatives by finding one with the best rating based on the given preferences. Each product's benefit to cost ratios was evaluated using data extracted from the economic model. Inulin offers the better benefit to cost ratio compared to agave spirit and inulin.

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Keywords: Economic model; SPSS; AHP; Parameter; Criteria; Alternatives, Pina; Eco-friendly; Agave; Benefit to cost ratio

1. Introduction

Agaves are a group of plants of the family Agavaceae, whose center of origin and diversity is Mexico [1][3]. Agave americana L. (AA) species are naturalized in Southern Africa [4]-[7]. They are medium-sized to large, rosulate, perennial, leaf succulents. Agave americana L. grow up to 2 m tall and are profusely proliferous through basal suckers [3],[4], [6]. Leaves are light blue with stout marginal spines throughout [8].

Agave is biodegradable. With its multiple uses, especially as a food, fiber, and alcoholic beverage, agave has held and still holds great economic and cultural importance for the society of Mexico [3], [9],[10]. Employment and industrialization that boosts rural development are inevitable within the agave industry. In Mexico alone, about 38,000 workers are employed in the industry [11] and latest science was brought to the agricultural process to save both the industry and the culture [12]. According to Rodrigues *et al* [13], from 2003 to 2011, industrialization of agave heads increased

by leaps of 412 900 tones, 998 400 tones, with a maximum of 1,125,100 in 2008 [14].

Basic applied research on agave plants has been done in the past [15]. The importance of agave to the South African economy has been recognized and a project to commercialize the growing of agave has been initiated in the Eastern Cape Province [16]. The Council of Scientific and Industrial Research (CSIR) studied AA plant processing that focused on understanding the AA plant biochemistry, fiber, textiles and potential for paper making. Important market research was also conducted on global demand for inulin as well as local demand by the textile industry of AA fibers for textile product production such as geotextiles and nonwoven products, [17]. Recently, CSIR carried out a research on “Technology development for establishing an agave plant industry in southern Africa” [18]. Research programs have also been launched in Mexico and other countries to evaluate the greater utilization of the agave plant [16].

The production of agave fiber starts with the harvesting of the leaves. Forty AA leaves are harvested annually and decorticated for green fiber that is useful for composites and technical textiles. However

according to CSIR the fiber contribution is approximately 1.5% [18] and the rest of the plant has no economic viability. Research has proved that it is not economic to process the fiber only [19]. This paper outlines the production of agave spirit, inulin and syrup from AA as a way of increasing the economic viability of the agave plants. Critical values are extracted from the economic model and used to derive the benefit to cost ratios of the products.

2. Background of Agave americana L.: South African case study

According to a local farmer agave bulbils were planted in the Eastern Cape Province as early as the 1860's. The poles of AA were used in making household fences on polling. Around the 1900s, agaves were also used to feed ostriches. From 1940s to 1960s, agaves were further planted in triangular shapes as a governmental agricultural policy for hedges, soil conservation and for income. A South African businessman formed Reinet Distillers for “tequila” production in 1998. This was due to a particularly devastating shortage of agave and many companies in Mexico had been pushed out of business [20][22]. However, the name “tequila” could not be used since the agave used was different from Agave tequilana Weber, grown within the boundaries delimited by the Mexican federal government [21][23]. This led to the brand creation of “agava silver” (clear spirit) and “agava gold” (aged spirit) [22] with strength of 45%. In 2008, the factory closed its doors [24]. With the abundance of agave within the 60km radius of the old factory [18], there is quest to revive the industry as a way of creating jobs for the people.

2.1. Agave cultivation

Land preparation and agave cultivation are labour intensive [25]. Bulbils are used as seed and the harvest cycle takes seven years. Under the traditional cultivation system, the average maturity time for agave is 10 years and harvest begins at 8 years [26]. Based on information from the farmers, the plant density is 3333 plants ha⁻¹. Irrigation is not required and manually operated hand tools are used for weeding. The hearts (*pina*) of the plants are harvested manually, where it takes seven minutes for an average worker to harvest the whole plant. The *pina* are transported to the distillery by trucks with an arbitrarily assigned transport distance of 4km as no data are available currently.

2.2. Spirit, inulin and syrup production processes

The number of kilograms of agave heads is an important parameter is spirit, inulin and syrup production. According to Yan et al 2011 [26], the total mass of the agave heads vary from 30 to 50kg per head. The mass is determined by the number of hectares harvested.

Initially, the heads are macerated into smaller pieces and inulin is mechanically extracted whilst solid fibers are filtrated away [18]. The macerated agave heads are hydrolysed or cooked for at least 32 h at 100°C, thereby breaking the inulin chains into fructose syrup [28][29]-[30]. Steel autoclaves with steam injection that lasts several hours are used for cooking agave heads [26]. High vacuum evaporation is used to extract the excess water from the juice [29]. After cooking the unhydrolysed syrup goes through milling to extract the juice (60%), generating 40% bagasse as a by-product [25]. Fermentation, distillation and ageing processes then generate agave spirit. The product is matured from 3 to 12 months in oak casks to produce agave spirit [1]. The spirit is bottled and distributed to the retailers. Figure 1 below shows the inputs, processes and outputs involved in *pina* processing into syrup and spirit.

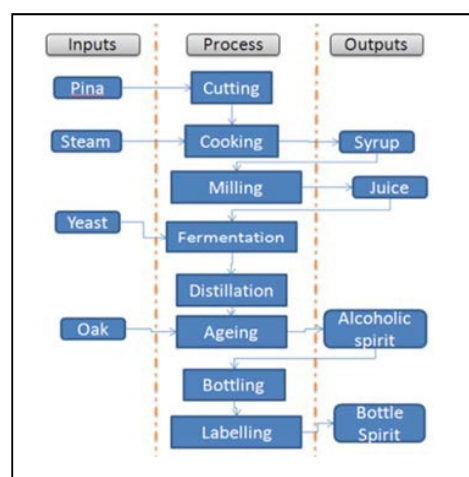


Fig. 1. Inputs, processes and outputs in *pina* processing

3. Methodology

Twenty questionnaires on factors that affect agave production were distributed among agave producers, industrial experts and researchers in Graaff-Reinet, South Africa. These form a criterion whereby respondents are agave experts directly involved in agave production and processing. Fourteen questionnaires were successfully completed and used for this analysis. SPSS software analyzed data from the fourteen respondents on factors that affect agave processing using a scale of

1,3,5,7 and 9. Calculations using the weighted average score formula determined the weights of the factors. A weighted average score is obtained by multiplying each data point by its weight, summing the results, and dividing the result by the sum of the weights. The analyzed data was used as input into the AHP multiple criteria decision-making tool.

On the other hand literature review on agave production and processing was used to determine the input and output parameters of agave spirit, inulin and syrup production. Most importantly, interviews with nine industrial experts investigating the interrelationships between input and output parameters were successfully carried out. Data gleaned was used to build the economic model for agave *pina* processing in Microsoft excel spreadsheets.

4. Analytic Hierarchy Process Algorithm

The Analytic Hierarchy Process (AHP), a multi-criteria decision making tool is a mathematical theory for deriving ratio scale priority vectors from positive reciprocal matrices with entries established by paired comparisons [31][32]. Paired comparisons judgments from a fundamental scale of absolute numbers are entered in a reciprocal matrix. Their numerical values and corresponding intensities are: 1=equal, 3=moderately dominant, 5=strongly dominant, 7=very strongly dominant and 9= extremely dominant, along with intermediate values for compromise and reciprocals for inverse judgments and even using decimals to compare homogeneous elements whose comparison falls within one unit [32][33]. A positive n by n matrix is reciprocal if $a_{ji} = 1/a_{ij}$ [34].

The AHP uses a principal Eigenvalue Method (EM) to derive priority vectors [31][35]. According to Saaty 1998 [31], the priority vector is denoted by $w = (w_1, w_2, \dots, w_n)^T$ whilst the judgement matrix is denoted as $A = (a_{ij})$, $a_{ji} = 1/a_{ij}$, $a_{ii} = 1$, $i, j = 1, 2, \dots, n$. EM solves for the principal eigenvector in $Aw = \lambda_{max}w$, where λ_{max} is the principal eigenvalue of A . The EM solution is given by

$$w = \lim_{k \rightarrow \infty} \left(\frac{A^k e^T}{e^T A^k e^T} \right),$$

where $e = (1, 1, \dots, 1)$.

5. Example

The structuring of a decision involves a goal, a set of criteria and a set of alternatives to choose from [32][36]. Using the AHP model, the problem is decomposed into a hierarchy of criteria and alternatives. The overall goal is to choose a product. There are six criteria: cycles of shortage of *pina* (C_1), cycles of surplus *pina* (C_2), availability of foreign market (C_3), availability of

domestic market (C_4), labor cost (C_5) as well as capital (C_6). Cycles of shortage of *pina* refers to the period when a generation of plants of a certain age group is lost probably due to pests invasion whilst the surplus of agave is when plants that are lying idle with no buyers. The price of agave decreases and farmers neglect to monitor the plantations closely for pests and/or disease, which often lead to an outbreak.

Under each criterion there are three alternatives: spirit (A_1), inulin (A_2) and syrup (A_3). Computing the eigenvector determines the relative ranking of alternatives under each criterion. The pairwise matrix is raised to powers that are successively squared; the row sums are then calculated and normalized. During the iterations, the computer stops when the difference between these sums in two consecutive calculations is zero to four decimal places [37]. The judgment matrices and the corresponding priority vectors derived by using EM are as shown below

Comparing the criteria for importance with respect to the goal gives the priorities in EM values shown:

	C_1	C_2	C_3	C_4	C_5	C_6	EM
C_1	1.0	0.9	0.3	0.2	0.2	1.4	$\begin{pmatrix} 0.0606 \\ 0.0517 \\ 0.1334 \\ 0.1523 \\ 0.2379 \\ 0.3641 \end{pmatrix}$
C_2	1.1	1.0	0.2	0.1	0.2	1.4	
C_3	3.0	4.5	1.0	0.8	1.2	0.2	
C_4	4.5	6.5	1.3	1.0	0.7	0.2	
C_5	4.7	5.3	0.8	1.4	1.0	4.1	
C_6	0.8	0.7	0.2	6.3	0.2	1.0	

The most important criterion is capital (C_6) with EM value of 0.3641. On rating the alternatives with respect to the criteria, the following EM values are derived.

With respect to criterion C_1 :

	A_1	A_2	A_3	EM
A_1	1	9	1/9	$\begin{pmatrix} 0.2319 \\ 0.0782 \\ 0.6899 \end{pmatrix}$
A_2	1/7	1	1/3	
A_3	9	3	1	

With respect to criterion C_2 :

	A_1	A_2	A_3	EM
A_1	1	5	1/3	$\begin{pmatrix} 0.3230 \\ 0.1105 \\ 0.5666 \end{pmatrix}$
A_2	1/5	1	1/3	
A_3	3	3	1	

With respect to criterion C_3 :

	A_1	A_2	A_3	EM
A_1	1	9	7	$\begin{pmatrix} 0.7854 \\ 0.0658 \\ 0.1488 \end{pmatrix}$
A_2	1/9	1	1/3	
A_3	1/7	3	1	

With respect to criterion C_4 :

$$\begin{matrix} A_1 & A_2 & A_3 & EM \\ A_1 & \begin{pmatrix} 1 & 1/9 & 1/7 \\ 9 & 1 & 5 \\ 7 & 1/5 & 1 \end{pmatrix} & \begin{pmatrix} 0.0510 \\ 0.7219 \\ 0.2271 \end{pmatrix} \end{matrix}$$

With respect to criterion C_5 :

$$\begin{matrix} A_1 & A_2 & A_3 & EM \\ A_1 & \begin{pmatrix} 1 & 9 & 3 \\ 1/9 & 1 & 7 \\ 1/3 & 1/7 & 1 \end{pmatrix} & \begin{pmatrix} 0.7006 \\ 0.2148 \\ 0.0846 \end{pmatrix} \end{matrix}$$

With respect to criterion C_6 :

$$\begin{matrix} A_1 & A_2 & A_3 & EM \\ A_1 & \begin{pmatrix} 1 & 9 & 7 \\ 1/9 & 1 & 3 \\ 1/7 & 1/3 & 1 \end{pmatrix} & \begin{pmatrix} 0.7903 \\ 0.1377 \\ 0.0720 \end{pmatrix} \end{matrix}$$

The overall ranking of the product alternatives are evaluated by multiplying the eigenvector of alternatives over each criterion by the criteria vector as shown below.

$$\begin{matrix} C_1 & C_2 & C_3 & C_4 & C_5 & C_6 & EM \\ A_1 & \begin{pmatrix} 1.0 & 0.9 & 0.3 & 0.2 & 0.2 & 1.4 \\ 1.1 & 1.0 & 0.2 & 0.1 & 0.2 & 1.4 \\ 3.0 & 4.5 & 1.0 & 0.8 & 1.2 & 0.2 \end{pmatrix} & \begin{pmatrix} 0.0606 \\ 0.0517 \\ 0.1334 \\ 0.1523 \\ 0.2379 \\ 0.3641 \end{pmatrix} \end{matrix} * \begin{pmatrix} 0.0606 \\ 0.0517 \\ 0.1334 \\ 0.1523 \\ 0.2379 \\ 0.3641 \end{pmatrix} = \begin{pmatrix} 0.5978 \\ 0.2304 \\ 0.1719 \end{pmatrix}$$

The agave spirit (A_1), is the highest ranked product in this category with an EM value of 0.5978.

6. Results and discussion

6.1. The product decision model

The resultant product decision model in Fig 2, involves a goal, a set of criteria (C_1, C_2, C_3, C_4, C_5 and C_6) and a set of alternatives (A_1, A_2 , and A_3) is shown in Fig 2.

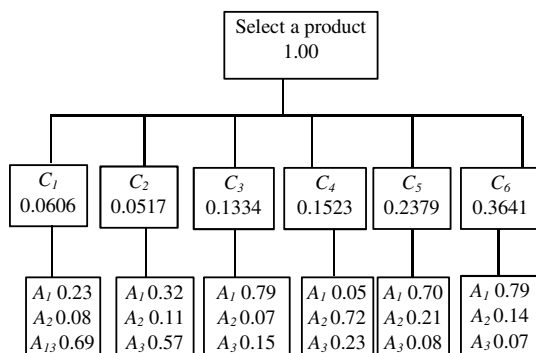


Fig. 2. The product decision model

The model shows all the respective weights for each attribute. Capital (C_6) is the highest ranking among the factors that affect agave processing. Loans can be issued to potential processors for investment.

6.2. The economic model

Appendix A.1 shows the economic model for the production of spirit, inulin and syrup respectively. The main life cycle stages considered are shown in Fig 1. Input and output parameters for each product; product specifications, production as well as product costing are summarized Ganduri [19]. The model provides an estimation of the cost and profit associated with the particular activity involved in agave *pina* processing.

6.3. Benefits to cost ratios

Critical values are extracted from the economic model and used to derive the benefit to cost ratios of the products. The benefit to cost ratio is calculated by dividing the normalized cost of production per litre of the alternative by its respective EM value. The results are shown in Fig 3.

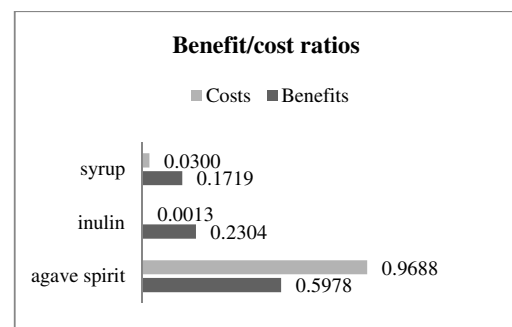


Fig. 3. Benefit/cost ratios

Inulin has the highest benefit to cost ratio. This is due to low capital investment required as compared to other products. From the economic model, 1.73kg of inulin is obtained from 1kg of agave head. South Africa alone needs 200 tonnes of inulin per annum according to SARS import/export data. This implies that, in order to meet the demand, approximately 115607kg of *pina* should be harvested and processed from approximately 2ha of land per annum.

6.4. Capital investment

Spirit being the main value added product is capital intensive. According to the AACE International [38], estimated total capital requirements is a sum of total plant cost, start-up and other pre-production costs, working capital and land. In this scenario, land is leased

to the processors by the government. From the cash flow generated by the economic model approximately R4 400 000, R3 100 000 and R1 000 000 can be invested for spirit, syrup and inulin production respectively.

6.5. Payback period

Critical data captured from the economic model shows that the time required to recover from the initial investment in year zero is seven years. This is because; in the seventh year sales of inulin, syrup and spirit commence hence more income is generated.

7. Conclusion

A hybrid approach has been used for the product selection problem using the AHP and the economic model. The AHP is used to narrow down all possible product alternatives in the agave processing industry by removing those whose weights are smaller than a pre-determined value obtained under certain circumstances. The economic model shows the product specifications, production inputs and outputs, product costing as well as the cash flow in agave *pina* processing. The final product alternative is selected by using benefit to cost ratio considering the cost of production per litre of inulin, syrup and spirit against the alternative EM values. The economic model shows that the production of agave spirit, inulin and syrup is feasible. The next stage will be to evaluate different scenarios to represent the combination of each of the processes. The economic model will be used for sensitivity analysis to compare how different variables affect the outcome and used for potential investor's decision making.

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A.1. Economic model for agave spirit, inulin and syrup production

Table 1. Spirit production model

Spirit input cost	1885918.53	R
Distillation & yeast cost	118238.18	kg
Bottling & labelling cost	116745.47	R
Cost of Bottles	1583841.60	R
Litres of spirit	65993.40	R
Income	8799120.00	R
Profit	6815961.09	R
Cost of production	28.58	R/litre

Table 2 Syrup production model

Syrup Input cost	97240.38	R
Band saw running cost	183.32	R/hour
Steamer running cost	1000.00	R/hour
Labour cost	2933.04	R
Milling cost	19798.02	R
Pina cost	73326.00	R
Syrup	109989.00	litre
Income syrup	18918108.00	R
Profit	18820867.63	R
Cost of production	0.88	R/litre

Table 3 Inulin production model

Inulin Input cost	5667.95	R
Transport cost	412.46	R
Band saw running cost	183.32	R
Chipper running cost	183.32	R
Labour cost	3989.12	R
Filtration cost	183.32	R
Pina cost	73.33	R
Drying cost	183.32	R
Inulin in kg	106249.37	kg
Inulin value	5949964.94	R
Profit	5944296.99	R
Cost of production	0.04	R/litre